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(54) State of Charge Indicator for Deep-Cycle Applications

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STATE OF CHARGE INDICATOR FOR DEEP-CYCLE APPLICATIONS

ABSTRACT OF THE DISCLOSURE

A state of charge indicator (10) monitors a voltage produced by a depletable energy source (11) and provides an indication when the state of charge of the depletable energy source (11) falls below a predetermined threshold. The state of charge indicator (10) includes an input circuit (13) for sensing the voltage and producing a plurality of tap voltages. The state of charge indicator (10) further includes a monitor circuit (65) for comparing each tap voltage with a corresponding threshold voltage and producing a result for each tap voltage falling below its corresponding threshold. The state of charge indicator (10) still further includes a storage device (75, 95, 115) for storing each result and producing an accumulated status and an output circuit (152) for producing the indication when the accumulated status exceeds an accumulated status threshold.

STATE OF CHARGE INDICATOR FOR DEEP-CYCLE APPLICATIONSBACKGROUND OF THE INVENTION

5 The present invention generally relates to a state of charge indicator for providing an indication when the state of charge of a depletable energy source falls below a predetermined threshold. The present invention is more particularly directed to a state of charge indicator for monitoring a voltage produced by a battery used in a deep cycle application and producing an indication when the state of charge of the battery falls below a predetermined threshold.

10 The state of charge of a depletable energy source such as a battery is an indication of the relative amount of useable energy remaining in the battery. The state of charge is given as a percentage equal to the ratio of the present amount of useable energy remaining in the battery to the amount of useable energy in the battery when it is fully charged. Thus, a fully-charged battery has a 100% state of charge, a fully-discharged battery has a 0% state of charge, and a battery charged to a level equal to one-half its full state of charge has a 50% state of charge.

15 Batteries are often used in deep cycle applications to provide electrical energy to power electrical devices such as electric motors or emergency lighting. In deep cycle applications, batteries are routinely and repetitively discharged to a relatively low state of charge and recharged to a near-100% state of charge. In other applications, batteries such as starting batteries in automobiles, for example, are used only intermittently, to supply electrical energy to the starter motor of the automobile. Aside from these momentary intermittent usages, such batteries are generally maintained near 100% state of charge. Deep cycle applications, in contrast, routinely discharge the battery to a low state of charge during normal usage.

Typical deep cycle applications for a battery include providing power to an electric trolling motor in a fishing boat, providing power to the electric drive system of a battery-operated wheelchair, or emergency power for security systems. In such applications, the battery may be required to supply current for several hours. Supplying this current will discharge the battery to a relatively low state of charge. Later, the battery may be recharged to a nearly 100% state of charge. This same cycle of discharging and recharging the battery may be repeated many times over the life of the battery.

In view of these typical applications, it would be advantageous to provide a battery with a state of charge indicator. Such an indicator would provide a visible or audible indication when the state of charge of the battery has fallen below a predetermined threshold. The indication would inform a user of the low state of charge condition and the impending need to recharge the battery. The indication reduces the risk of discharging the battery to a level insufficient to provide usable power or to a level at which irreversible damage to the battery may occur.

There is a need for a state of charge indicator for deep cycle applications which can provide a timely indication of a low state of charge condition when the battery is subjected to a wide range of load currents.

There is also a need for a low state of charge indicator which is not sensitive to voltage fluctuations which might cause the state of charge indication to fluctuate about the low state of charge set point. The state of charge indicator may provide, for example, an indication when the battery state of charge falls below a set point of 50% state of charge. As the state of charge of the battery falls below this set point, a transient in the current supplied by the battery may cause the voltage supplied by the battery to falsely indicate a state of charge above the set point. Accordingly, there is a need for a state of charge indicator which latches the low state of charge indication and does not reset the latched

condition until the battery has been recharged to well above the state of charge setpoint level.

5 In general, the state of charge indicator of the present invention measures battery voltage and compares the battery voltage to different preset voltage values at  
10 corresponding specified time intervals and evaluates if the battery voltage is above or below the preset voltage values. The preset voltage values and corresponding specified time intervals are empirically determined for a  
15 given type of battery and state of charge setpoint level. The results of the evaluations are placed into, for example, shift registers. The number of low indications within the shift registers are summed and evaluated. If the sum exceeds a predetermined accumulated status  
20 threshold, an output indication is provided, indicating a low state of charge condition. If the low state of charge indication is provided, this output indication is latched until the state of charge indicator detects that the battery has been recharged to well above the predetermined state of charge setpoint level.

#### SUMMARY OF THE INVENTION

25 The present invention provides a state of charge indicator for monitoring the voltage of a depletable energy source and providing an indication when the state of charge of the depletable energy source falls below a predetermined threshold level. The state of charge indicator includes an input system for sensing the voltage of the depletable energy source and providing a signal to a monitor system comprising several stages. Each stage of the monitor  
30 system compares the sensed voltage signal to the corresponding threshold voltage for that stage. Each stage further comprises a storage system for storing the result of the comparison at regular time intervals for that stage. The storage system stores a finite number of results  
35 representing the short term history of comparisons for that stage. The state of charge indicator further includes an output system coupled to the storage system of all individual stages. The stored results of all the stages

are summed to produce an accumulated status. The output system produces the indication when the accumulated status exceeds the accumulated status threshold. The state of charge indicator further provides a recharge monitor system coupled to the input system for determining if the depletable power source has been recharged. The output system continues to produce the indication until the accumulated status no longer exceeds the accumulated status threshold and the recharge monitor system indicates that the depletable energy source has been recharged.

The present invention provides a state of charge indicator for monitoring a voltage produced by a depletable energy source and providing an indication when the state of charge of the depletable energy source falls below a predetermined threshold. The state of charge indicator includes input system for sensing the voltage and producing a plurality of tap voltages and monitor system coupled to the input system for comparing each tap voltage with a corresponding threshold voltage and producing a result for each tap voltage falling below its corresponding threshold voltage. The state of charge indicator still further includes storage system for storing each result at corresponding time intervals and producing an accumulated status and output system coupled to the storage system for producing the indication in response to the accumulated status exceeding an accumulated status threshold.

In accordance with the present invention, the input system of the state of charge indicator may further produce a recharge tap voltage. The state of charge indicator of the present invention may further comprise recharge monitor system for forcing the output system to continue providing the indication when the accumulated status no longer exceeds the accumulated status threshold and when the recharge tap voltage remains below a recharge threshold.

The present invention further provides a state of charge indicator for providing an indication when the state of charge of a battery falls below a predetermined threshold level. The state of charge indicator includes

input system for sensing a voltage produced by the battery and producing a plurality of tap voltages and a plurality of monitor stages coupled to the input system and having a common output. Each monitor stage includes sensing system  
5 for sensing one tap voltage of the plurality of tap voltages and producing a result when the one tap voltage falls below a predetermined threshold. Each monitor stage further includes storage system coupled to the sensing system for storing each result at corresponding time  
10 intervals, the storage system having an output coupled to the common output for supplying an accumulated status. The state of charge indicator further includes comparator system coupled to the common output for producing a signal when the accumulated status exceeds a predetermined  
15 accumulated status threshold and output system coupled to the comparator system for providing the indication in response to the signal.

The present invention still further provides a method of monitoring a voltage produced by a depletable energy  
20 source and producing an indication when the state of charge of the depletable energy source falls below a predetermined threshold. The method includes the steps of sensing the voltage and producing a plurality of tap voltages, comparing each tap voltage to a corresponding threshold  
25 voltage and producing a result for each tap voltage falling below its corresponding threshold voltage, producing an accumulated status of the results, and providing the indication when the accumulated status exceeds an accumulated status threshold.

30 BRIEF DESCRIPTION OF THE DRAWINGS

The features of the present invention which are believed to be novel are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may best be understood by  
35 making reference to the following description taken in conjunction with the accompanying drawing, in the sole figure of which identical reference characters indicate identical elements, and wherein the sole figure is a

schematic diagram illustrating the manner in which the present invention may be implemented in hardware form in accordance with the preferred embodiment of the present invention.

5     DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the sole figure, it illustrates a state of charge indicator 10 embodying the present invention. The state of charge indicator 10 is of the type which monitors a voltage produced by a depletable energy source such as a battery 11 and provides an indication when the state of charge of the depletable energy source falls below a predetermined threshold.

10     The state of charge indicator 10 generally includes input system 13, a threshold generating system 46, monitor system 65, comparator system 134 and output system 152. The monitor system 65 may include one or more monitor stages such as first monitor stage 66, second monitor stage 68 and third monitor stage 70. The state of charge indicator 10 also includes recharge monitor system 168 and clock system 178.

20     The input system 13 of the state of charge indicator 10 includes a positive input 12, a negative input 14, and resistors 18, 24, 30, 36, and 42. The positive input 12 and the negative input 14 are preferably coupled to the terminals of the depletable energy source 11. The negative input 14 preferably forms or provides system ground. The positive input 12 is coupled to the first end 16 of resistor 18. The second end 20 of the resistor 18 is coupled to the first end 22 of resistor 24. The second end 26 of the resistor 24 is coupled to the first end 28 of resistor 30. The second end 32 of the resistor 30 is coupled to the first end 34 of resistor 36. The second end 38 of the resistor 36 is coupled to the first end 40 of resistor 42. The second end 44 of resistor 42 is coupled to the negative input 14. Resistor 18, resistor 24, resistor 30, resistor 36, and resistor 42 form input system 13 for sensing the voltage between the positive input 12



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and the negative input 14 and producing a plurality of tap voltages.

Also coupled to the positive input 12 is the threshold generating system 46. The threshold generating system 46 includes a diode 48, a resistor 52, zener diodes 50, 60 and 62, and capacitor 58. The anode of the diode 48 is coupled to the positive input 12. The cathode of the diode 48 is coupled to the cathode of the zener diode 50 and a first end 53 of the resistor 52. The anode of the zener diode 50 is coupled to the negative input 14. The second end 56 of the resistor 52 is coupled to a VCC node 54. The VCC node 54 is preferably provided with a voltage of +5 volts and provides positive supply voltage to other components of the state of charge indicator 10. The capacitor 58 is coupled between the second end 56 of the resistor 52 and the negative input 14. The cathode of the zener diode 60 is coupled to the second end 56 of the resistor 52. The anode of the zener diode 60 is coupled to a reference node 64. The cathode of the zener diode 62 is coupled to the reference node 64. The anode of the zener diode 62 is coupled to the negative input 14.

In the operation of the threshold generating system 46, a reference voltage is provided at the reference node 64. This reference voltage is preferably temperature and current compensated as is well-known in the art. This reference voltage is used for producing threshold voltages corresponding to each tap voltage produced by the input system 13.

The reference node 64 is coupled to monitor system 65. The monitor system 65 includes first, second and third monitor stages 66, 68 and 70.

The first monitor stage 66 includes monitor system 74 and storage system 75. The storage system 75 includes shift register 82 and resistors 88a, 88b, 88c, 88d, 88e, 88f, 88g, and 88h. In the first monitor stage 66, a resistor 72 is coupled between the reference node 64 and the monitor system 74. The monitor system 74 includes an operational amplifier 76 and a feedback resistor 78. The

output of the monitor system 74 is coupled to an input 80 of shift register 82. The shift register 82 also has a clock input 84. The shift register 82 further has outputs 86a, 86b, 86c, 86d, 86e, 86f, 86g, and 86h coupled to resistors 88a, 88b, 88c, 88d, 88e, 88f, 88g, and 88h, respectively, which have a common connection to form an output 90 of the first monitor stage 66.

The second monitor stage 68 includes monitor system 94 and storage system 95. The storage system 95 includes shift register 102 and resistors 108a, 108b, 108c, 108d, 108e, 108f, 108g, and 108h. In the second monitor stage 68, a resistor 92 is coupled between the reference node 64 and the monitor system 94. The monitor system 94 includes an operational amplifier 96 and a feedback resistor 98. The output of the monitor system 94 is coupled to an input 100 of the shift register 102. The shift register 102 also has a clock input 104. The shift register 102 has outputs 106a, 106b, 106c, 106d, 106e, 106f, 106g, and 106h coupled to resistors 108a, 108b, 108c, 108d, 108e, 108f, 108g, and 108h, respectively, which have a common connection to form an output 110 of the second monitor stage 68.

The third monitor stage 70 includes monitor system 114 and storage system 115. The storage system 115 includes shift register 122 and resistors 128a, 128b, 128c, 128d, 128e, 128f, 128g, and 128h. In the third monitor stage 70, a resistor 112 is coupled between the reference node 64 and the monitor system 114. The monitor system 114 includes an operational amplifier 116 and a feedback resistor 118. The output of the monitor system 114 is coupled to an input 120 of a shift register 122. The shift register 122 also has a clock input 124. The shift register 122 has outputs 126a, 126b, 126c, 126d, 126e, 126f, 126g, and 126h coupled to resistors 128a, 128b, 128c, 128d, 128e, 128f, 128g, and 128h, respectively, which have a common connection to form an output 130 of the third monitor stage 70.

The output 90 of the first monitor stage 66, the output 110 of the second monitor stage 68 and the output 130 of the third monitor stage 70 are coupled together to

form a common output 132. The common output 132 is coupled to the comparator system 134. The comparator system 134 includes a resistor 136, an operational amplifier 138, a feedback resistor 140 and a resistor 144. The inverting  
5 input of the operational amplifier 138 is coupled to the reference node 64. The operational amplifier 138 has an output 142 coupled to a first end 146 of the resistor 144. The second end 148 of the resistor 144 is coupled to node 150.

10 Node 150 is also coupled to the output system 152. The output system 152 includes a latch system 154 and an output device 162. The latch system 154 includes an operational amplifier 156 and a feedback resistor 158. The output of the latch system 154 is coupled to a resistor  
15 160. The resistor 160 is further coupled to the output device 162 which may be a switching device such as a field effect transistor. In the embodiment shown in the figure, the output device 162 is coupled to a light emitting diode 164. The anode of the light emitting diode 164 is coupled  
20 to a current limiting resistor 166. The resistor 166 is coupled to the positive input 12. Thus, when the output system 152 provides an indication of low state of charge, light emitting diode 164 is illuminated. The low state of charge indication may be any visual, electrical, audible,  
25 or other signal capable of indicating the low state of charge condition to the user.

The state of charge indicator 10 also includes recharge monitor system 168. The first end 40 of resistor 42 of the input system 13 is also coupled to the recharge  
30 monitor system 168. The recharge monitor system 168 includes a resistor 170, an operational amplifier 172, a feedback resistor 174 and a resistor 176. The inverting input of the operational amplifier 172 is coupled to the reference node 64. The recharge monitor system 168 has an output 173 coupled to a first end 175 of the resistor 176.  
35 The second end 177 of the resistor 176 is coupled to node 150.

Lastly, the state of charge indicator 10 includes a clock system 178 for providing a plurality of clock signals. Clock system 178 includes a resistor 180, a capacitor 182 and a clock generator 184. The clock generator 184 provides clock signals on outputs 186, 188, and 190. Output 186 is coupled to the clock input 84 of the shift register 82. Output 188 is coupled to the clock input 104 of the shift register 102. Output 190 is coupled to the clock input 124 of the shift register 122. The clock generator 184 generates clock signals at a rate determined by the values of resistor 180 and capacitor 182. Preferably, the frequencies of clock signals provided on outputs 186, 188 and 190 are different. Preferably the frequency of the clock signal provided on output 190 is lower than the frequency of the clock signal provided on output 188. Also, preferably the frequency of the clock signal provided on output 188 is lower than the frequency of the clock signal provided on output 186.

For monitoring a voltage produced by a depletable energy source and providing an indication when the state of charge of the depletable energy source falls below a predetermined threshold, positive input 12 and negative input 14 are coupled to the output terminals of the depletable energy source. The resistors 18, 24, 30, 36, and 42 form a voltage divider. The voltage divider produces tap voltages proportional to the voltage between positive input 12 and negative input 14. A first tap voltage is produced at the second end 20 of the resistor 18 and supplied to the inverting input of the operational amplifier 76 of the monitor system 74 of the first monitor stage 66. The monitor system 74 forms a comparator with hysteresis, well-known in the art. The magnitude of the tap voltage supplied to the inverting input of the operational amplifier 76 is compared with a threshold voltage at the noninverting input of operational amplifier 76. When the tap voltage supplied to monitor system 74 is greater than the threshold voltage supplied to the monitor system 74, the output of the monitor system 74 will be a

5 voltage corresponding to a logical 0 value. When the tap voltage supplied to the monitor system 74 is less than the threshold voltage supplied to the monitor system 74, as when the state of charge of the depletable energy source coupled to positive input 12 and negative input 14 is diminished in value, the output of the monitor system 74 will be a voltage corresponding to a logical 1 value.

10 The output produced by the monitor system 74 is supplied to the input 80 of the shift register 82. The shift register 82 preferably includes a plurality of storage locations, each storage location having an associated order, the order being from highest to lowest. In response to a clock signal received at clock input 84, the shift register 82 discards the contents of the highest-ordered storage location, sequentially moves the contents of each storage location to the next highest-ordered storage location, and stores the logical value supplied at input 80 in the lowest ordered storage location. Preferably, shift register 82 includes eight such storage locations. The contents of each such storage location is supplied to outputs 86a, 86b, 86c, 86d, 86e, 86f, 86g, and 86h, respectively. A voltage corresponding to the sum of the contents of the eight storage locations of the shift register 82 is supplied to output 90 of first monitor stage 66.

25 Thus, the first monitor stage 66 compares the tap voltage at the second end 20 of the resistor 18 with a corresponding threshold voltage and produces a result. Responsive to clock signals from the clock system 178, the first monitor stage 66 stores the results of the eight preceding comparisons. The results of these comparisons are summed and a voltage corresponding to the sum is provided at the output 90.

30 In a similar manner, the second monitor stage 68 compares the tap voltage at the second end 26 of the resistor 24 with a corresponding threshold voltage and produces a result. Responsive to clock signals from the clock system 178, the second monitor stage 68 stores the

results of the eight preceding comparisons. The results of these comparisons are summed and a voltage corresponding to the sum is provided to the output 110.

5 In like manner, the third monitor stage 70 compares the tap voltage at the second end 32 of the resistor 30 with a corresponding threshold voltage and produces a result. Responsive to clock signals from the clock system 178, the third monitor stage 70 stores the results of the eight preceding comparisons. The results of these  
10 comparisons are summed and a voltage corresponding to the sum is provided to the output 130.

As noted above, the clock signals provided at the outputs 186, 188 and 190 of the clock system 178 to the first monitor stage 66, the second monitor stage 68, and  
15 the third monitor stage 70, respectively, preferably have differing frequencies. Preferably, the clock signal provided to the first monitor stage 66 has a greater frequency than the clock signal provided to the second monitor stage 68 and the clock signal provided to the  
20 second monitor stage 68 has a greater frequency than the clock signal provided to the third monitor stage 70. Thus, the first monitor stage 66, which compares the tap voltage having the highest voltage magnitude which corresponds to the threshold voltage having the lowest voltage magnitude,  
25 stores the results of the comparisons most frequently. Similarly, the third monitor stage 70, which compares the tap voltage having the lowest voltage magnitude which corresponds to the threshold voltage having the highest voltage magnitude, stores the results of the comparison  
30 least frequently.

During the discharge cycle of a battery, the battery voltage decreases as the battery state of charge decreases for a given discharge rate. Similarly, the voltage decreases as the rate of discharge increases for a given  
35 state of charge condition. Each stage compares the battery voltage to different threshold voltages at different rates. A relatively low battery voltage can be attributed to two conditions: the rate of discharge is high or the battery

state of charge is low. Both of these conditions necessitate that the sampling rate for the stage with the lower threshold voltage be relatively fast in order that the battery monitor indicates before the battery state of charge falls well below the predetermined state of charge threshold. Conversely, a relatively high battery voltage indicates that the battery state of charge is high or that the discharge rate is low. These two conditions necessitate that the sample rate for the stage with the higher threshold voltage be relatively slow. In this second scenario, there is plenty of time to identify the low state of charge condition before the battery state of charge falls below the predetermined state of charge threshold. Through proper selection of threshold voltages and storage rates, a given state of charge can be correctly identified for varying discharge conditions to a high level of precision.

The embodiment of the present invention shown in the drawing includes three monitor stages, the first monitor stage 66, the second monitor stage 68, and the third monitor stage 70. As will be appreciated by those skilled in the art, a different number of monitor stages may be utilized without departing from the present invention. The number of stages required is dependent upon the application for which the battery coupled to the state of charge indicator 10 is used. More monitor stages will be required in applications which have a broad current range, i.e., a current range from 0 to 150 amperes during use or in applications in which the current supplied by the battery varies greatly, i.e., the current fluctuates during use from 0 to 75 to 25 to 100 amperes. Also, the state of charge indicator will require more stages for applications in which it is desirable to increase the accuracy of the state of charge indicator.

The clock frequencies supplied by the clock system 178 and the predetermined threshold voltages corresponding to each tap voltage are chosen based on known characteristics of the battery to which the state of charge indicator 10 is

coupled. The frequencies and threshold voltages are also preferably chosen so that state of charge indicator 10 will provide the state of charge indication at any predetermined level from 0% to 100% state of charge and to some level of precision, such as a 5% band about the predetermined state of charge level.

The comparator system 134 monitors the accumulated status produced at the common output 132 of the first monitor stage 66, the second monitor stage 68 and the third monitor stage 70. The accumulated status is supplied to the noninverting input of the operational amplifier 138. The reference voltage on the reference node 64 is supplied to the inverting input of the operational amplifier 138. When the voltage magnitude of the accumulated status is less than the voltage magnitude of the reference voltage at node 64, the output of the operational amplifier 138 corresponds to a logical 0 value. This logical 0 value indicates that the state of charge indicator has not detected a low state of charge condition. When the voltage magnitude of the accumulated status is greater than the reference voltage, the output of the operational amplifier 138 will have a value corresponding to a logical 1 value. This logical 1 value indicates that the state of charge indicator 10 has detected a low state of charge indication.

The recharge monitor system 168 monitors a recharge tap voltage produced at the second end 38 of the resistor 36. The recharge tap voltage is supplied to the noninverting input of the operational amplifier 172. The reference voltage is supplied on the reference node 64 to the inverting input of operational amplifier 172. When the recharge tap voltage has a voltage magnitude greater than the reference voltage supplied on the reference node 64 the output of the operational amplifier 172 has a logical 1 value. When the recharge tap voltage has a voltage magnitude less than the reference voltage, the output of the operational amplifier 172 has a logical 0 value. The logical 1 value at the output of the operational amplifier 172 indicates that the depletable energy source coupled



across the positive input 12 and the negative input 14 is charging or is fully charged. The logical 0 value at the output of the operational amplifier 172 indicates that the depletable energy source is not charging or is not fully charged. The recharge monitor system 168 is used for forcing the output device 162 to continue providing a low state of charge indication when the accumulated status no longer exceeds the accumulated status threshold and when the recharge tap voltage falls below the recharge threshold. Thus, the output of the operational amplifier 172 provides a recharge signal.

An important aspect of the present invention is provided by the latch system 154. The latch system 154 forms an output control system for controlling the output device 162 in response to the comparator system 134 and the recharge monitor system 168. The operation of the latch system 154 is shown in the truth table, Table I.

	<u>Previous Output (156)</u>	<u>Charging (172)</u>	<u>Accumulated Status (138)</u>	<u>Next Output (156)</u>
20	0	0	0	0
	0	0	1	1
	0	1	0	0
	0	1	1	1
	1	0	0	1
25	1	0	1	1
	1	1	0	0
	1	1	1	1

TABLE I

As will be noted from Table I, the next output, the output of the operational amplifier 156, is a function of the previous output, which is the output of the operational amplifier 156, the recharge signal, which is the output of the operational amplifier 172, and the accumulated status which is the output of the operational amplifier 138. When the next output has a logical 0 value, the output device 162 will not provide a low state of charge indication. Similarly, when the next output has a logical value 1, the

output device 162 will provide a low state of charge indication.

As can thus be seen in Table I, the state of the next output generally tracks the state of the accumulated status. However, where the accumulated status is a 0, indicating the battery does not presently have a low state of charge, and the charging output is a 0, indicating the battery is not recharging or fully charged, and the previous output was a 1, indicating a low state of charge, the next output remains a logical 1, indicating low state of charge. Thus, the state of charge indicator 10 is rendered insensitive to short-term fluctuations of the output voltage of the depletable energy source. Once the state of charge indicator 10 has detected a low state of charge and provided an indication through the output device 162, the low state of charge state is latched by the latch system 154. The latch system 154 is only reset by a logical 1 on the charging output, the output of the operational amplifier 172.

From the foregoing, it can be seen that the present invention provides a new and improved state of charge indicator for monitoring a voltage produced by a depletable energy source and providing an indication when the state of charge of the depletable energy source falls below a predetermined threshold. In addition, the state of charge indicator of the present invention assures that the low state of charge indication will continue to be provided until the depletable energy source has been recharged to well above the predetermined setpoint level.

While a particular embodiment of the present invention has been shown and described, modifications may be made, and it is therefore intended in the appended claims to cover all such changes and modifications which fall within the true spirit and scope of the invention.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE  
PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

- 1           1. A state of charge indicator (10) for providing an  
2           indication when the state of charge of a battery (11) falls  
3           below a predetermined threshold level, characterized by:  
4                 an input system (13) for sensing a voltage  
5                 produced by the battery (11) and producing  
6                 a plurality of tap voltages;  
7                 a plurality of monitor stages (66, 68, 70)  
8                 coupled to the input system and having a  
9                 common output (132), each monitor stage of  
10                the plurality of monitor stages (66, 68, 70)  
11                including a monitor system for sensing one  
12                tap voltage of the plurality of tap voltages  
13                and producing a result when the one tap  
14                voltage falls below a predetermined  
15                threshold and a storage system (75, 95, 115)  
16                coupled to the monitor system for storing  
17                each result, the storage system (75, 95,  
18                115) having an output (90, 110, 130) coupled  
19                to the common output (132) for supplying an  
20                accumulated status;  
21                a comparator system (134) coupled to the common  
22                output (132) for producing a signal when the  
23                accumulated status exceeds a predetermined  
24                accumulated status threshold; and  
25                an output system (152) coupled to the comparator  
26                system (134) for providing the indication in  
27                response to the signal.
- 1           2. A state of charge indicator (10) of claim 1,  
2           further characterized in that a recharge monitor system  
3           (168) is coupled to the input system (13) for monitoring  
4           one tap voltage of the plurality of tap voltages and  
5           generates a recharge signal when the one tap voltage of the  
6           plurality of tap voltages exceeds a recharge threshold.
- 1           3. A state of charge indicator (10) of claim 2,  
2           further characterized in that an output control system  
3           (152) is coupled to the comparator system (134), the output  
4           device (162) and the recharge monitor system (168)

5 responding to the comparator system (134) and the recharge  
6 monitor system (168) and controlling the output device  
7 (162) by forcing the output device (162) to continue  
8 providing the indication when the comparator system (134)  
9 no longer produces the signal.

1 4. A state of charge indicator (10) of claim 1,  
2 further characterized in that the storage system includes  
3 a plurality of storage locations (75, 95, 115) for storing  
4 a like plurality of the results, each storage location of  
5 the plurality of storage locations (75, 95, 115) having an  
6 associated order, the order being from highest to lowest,  
7 and wherein the storage system is responsive to a clock  
8 signal (84, 104, 124) for discarding the contents of the  
9 highest ordered of the storage locations, sequentially  
10 moving the contents of each storage location of the  
11 plurality of storage locations (75, 95, 115) to the next  
12 highest ordered storage location and storing the result in  
13 the lowest ordered of the storage locations, each storage  
14 location of the plurality of storage locations (75, 95,  
15 115) being coupled to the common output (132).

1 5. A state of charge indicator (10) of claim 4,  
2 further characterized in that the storage system (75, 95,  
3 115) includes a shift register (82, 102, 122) and each  
4 storage system of the plurality of monitor stages (66, 68,  
5 70) is coupled to a different clock signal of a plurality  
6 of clock signals (84, 104, 124) generated by the clock  
7 system (178).

1 6. A state of charge indicator (10) of claim 1,  
2 further characterized in that each monitor system of the  
3 plurality of monitor stages (66, 68, 70) is coupled to a  
4 different predetermined threshold of a plurality of  
5 predetermined thresholds generated by threshold generating  
6 system (46).

1 7. A method of monitoring a voltage produced by a  
2 depletable energy source (11) and producing an indication  
3 when the state of charge of the depletable energy source  
4 (11) falls below a predetermined threshold, characterized  
5 by:

6           sensing the voltage and producing a plurality of  
7           tap voltages;  
8           comparing each tap voltage of the plurality of  
9           tap voltages to a corresponding threshold  
10          voltage and producing a result for each the  
11          tap voltage falling below its corresponding  
12          threshold voltage;  
13          producing an accumulated status from the results;  
14          and  
15          providing the indication when the accumulated  
16          status exceeds an accumulated status  
17          threshold.

1           8. A method as defined in claim 7, further  
2           characterized by the step of periodically storing the  
3           results and combining the results to produce the  
4           accumulated status.

1           9. A method as defined in claim 8, further  
2           characterized by the step of providing a clock (178) for  
3           clocking the periodic storing of the results.

1           10. A method as defined in claim 7, further  
2           characterized by the step of monitoring one tap voltage of  
3           the plurality of tap voltages and generating a recharge  
4           signal when the one tap voltage of the plurality of tap  
5           voltages exceeds a recharge threshold.

1           11. A method as defined in claim 10, further  
2           characterized by the step of forcing the output system  
3           (152) to continue providing the indication when the  
4           accumulated status no longer exceeds the accumulated status  
5           threshold and when the one tap voltage does not exceed the  
6           recharge threshold.

